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源头流域氮的来源迁移与转化

Nitrogen Sources, Transports and Transformations in Headwater Catchment

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摘 要

过量施肥、化石燃料的燃烧等人类活动带来的氮负荷问题对陆地和水生生态系统的影响迅速扩大，引起了全世界的关注。当流域陆地生态体系的氮素饱和后，过量的氮素会通过地表径流和地下潜流排入溪流、湖泊、河流和海洋中。因为溪流直接迁移了流域体系过多的氮素，研究氮在溪流中的循环过程之前了解流域氮素流失到溪流的过程机制至关重要。因此，对五川流域氮素流失的过程机理进行研究以及探讨氮在溪流中的迁移转化行为，有利于阐明流域体系的氮在溪流中的循环过程。

本研究融合多学科知识，在 GIS 技术支持下，综合运用现场定位试验、模型模拟、同位素示踪等多种研究手段与方法，揭示了流域氮的地表流失、地下渗漏淋失等的迁移转化特征并量化，阐明了可溶性无机氮在溪流中的迁移转化过程。主要研究结论如下：

第一，氮的地表径流输出过程及机制。流域氮的地表径流输出主要受降雨、径流、土地利用和施肥状况的多种因素影响，表现出明显的季节性特征。污染物输出主要集中在 4-9 月。2004-2006 年地表径流各形态氮的总输出负荷逐年增加，总氮年输出负荷最小值是 2004 年的 37.11 kg N hm^{-2}，最大值是 2006 年的 108 kg N hm^{-2}。与五川流域年平均总氮输入 421.4 kg N hm^{-2} 相比，地表径流总氮输出平均为 68.35 kg N hm^{-2}，占总输入的 16.2%，其中降雨径流平均输出总氮 45.51 kg N hm^{-2}，占流域总氮输入的 10.8%，基流平均输出总氮 22.84 kg N hm^{-2}，占流域总氮输入的 5.4%。地表径流氮素流失量逐年递增，流失的氮排放到溪流河道中，使溪流氮负荷增加，水质恶化。形态组成上，溶解态氮占 TN 主要比例（DTN/TN=0.84）；在 DTN 中，DIN 占 89.5%，DON 仅占 10.5%；在 DIN 中，NO_3-N 占 65.5%，NH_4-N 占 34.5%。

第二，氮的淋失过程及机制。五川流域氮的渗漏淋失主要与施肥量、土壤类型、降雨等因素有关。氮淋失在降雨密集的 4–9 月较为严重。pH<5 的酸性土壤带正电荷致使铵氮更易向下淋洗造成“富集”，氮淋失以铵氮为主（约 40%）。利用校验后的 GLEAMS 模型，模拟得到 2004-2006 不同土地利用地块硝氮淋失量从 5.00 到 50.79 kg N hm^{-2} a^{-1} 不等。3 年中，流域加权土地面积总氮年渗漏淋

失负荷范围为 27.47-99.97 kg N hm^{-2}，平均渗漏淋失负荷为 69.13 kg N hm^{-2}。，地下渗漏淋失总氮占流域总氮输入（421.4 kg N hm^{-2}）的 16.4%；而 NO_3-N 年渗漏淋失负荷范围为 7.89-28.31 kg N hm^{-2}，平均 19.68 kg N hm^{-2}。，占流域 TN 输入的 4.67%。

第三，五川溪流氮的迁移和转化过程。硝氮与δ^{15}N、亚硝氮、溶解氧、溶解有机碳的变化关系表明溪流沿程硝化作用是氮在溪流河道的主要生物地球化学过程，也是溪流硝氮浓度沿程升高的主要原因。流域沿程耕地面积比例的增加和面源污染物随地表径流的排入也是溪流沿程铵氮和硝氮浓度升高，特别是铵氮浓度升高的主要原因之一。五川源头溪流较浅的河床为氮的迁移和转化提供了相对较活泼的载体。溪流是联接流域陆地和水体生态系统氮素的重要纽带。

关键词：氮； 来源与转化； 源头流域；

ABSTRACT

Human activities such as fertilizer application, fossil fuel combustion have resulted in increased nitrogen(N) loads for terrestrial and aquatic ecosystems causing worldwild concern. As terrestrial ecosystems become saturated with N, excess N moves with surface runoff and groundwater flow to streams, lakes, rivers, and coastal oceans. Headwater streams convey water and nutrients to larger streams and despite their relatively small dimensions, play a disproportionately large role in nitrogen transformations on the landscape. Quantitative information on N cycling in streams is needed to understand how N loading from watersheds for streams transporting much of this N directly from terrestrial ecosystems.

In this study, Water quality monitoring, field measurement, mechanism model, isotope tracing method and GIS technique were linked to estimate N flux of streamflow discharge and leaching. The work provides a sound understanding of the influence of surface runoff and groundwater flow on stream N, and highlights transformation and biogeochemistry behavior of dissolved nitrogen in stream.

First, annual and seasonal patterns of N loss in streamflow were evaluated based on monitoring data of water quality and flow in 2004-2006. N loss in stormflow was positively related to the ratio of arable land, and varied greatly among the representative subwatersheds, reflecting the differences in precipitation, land cover, and N inputs. The annual maximum total N export was 108 kg N hm^{-2} of 2006, and the minimum was 37.11 kg N hm^{-2} of 2004. Compared to average annual N inputs, 421.4 kg N hm^{-2}, average annual total N loss of these three years from streamflow was 68.35 kg N hm^{-2}. Storm runoff conveyed total N 45.51 kg N hm^{-2}, which contributed to 10.8% of total N inputs and baseflow conveyed total N 22.84 kg N hm^{-2}, which contributed to 5.4% of total N inputs. The riverine export of dissolved total nitrogen (DTN), formed 84% of the total flux and the dissolved inorganic nitrogen (DIN) formed 89.5%of DTN. NO_3-N and NH_4-N were main forms of DIN, contributed to 65.5% and 34.5%respectively.

Second, N leaching in Wuchuan catchment was evaluated using shallow water concentration and GLEAMS (*Groundwater Loading Effects of Agricultural Management Systems*) model. The variation of N concentration in shallow aquifers indicated that higher fertilization under land of vegetable and commercial crops in spring provided the larger N source. Meanwhile, low hydrologic table in winter (dry season) resulted in a concentrating effect of N concentration. The peak N export in leachate occurred between July to September when rainfall intensity was very high. N leaching was dominated by ammonium form (40%) rather than nitrate form (20%), as a result of acid soil being positively charged with electricity when $pH<5$. Nitrate export rate differed substantially with landuse and varied from 5.00 to 50.79 kg N hm^{-2} in 2004-2006, with the area-weighted value of 19.70 kg N hm^{-2} accounting for 4.7% of total N inputs in Wuchuan catchment.

Third, This study found that NH_4 and NO_3 concentrations in streams were in dynamic balance, controlled by input, nitrification, biological uptake, sorption, and regeneration. The relationship between NO_3-N with δN^{15}, NO_2-N, dissolved oxygen, dissolved organic carbon indicated that nitrification was the main biogeochemical process of Wuchuan stream, which played a large role in increasing nitrate levels during stream transport over a relatively short distance. With the area of arable land increment, non-point pollution discharging into the stream was also responsible for NH_4-N and NO_3-N concentration downstream rising, especially for NO_3-N. In headwater streams, uptake and removal processes occur mainly on sediments and biofilms covering submerged surfaces. Thus, the shallow depths and high surface-to-volume ratios characteristic of the Wuchuan stream supply a relative reactive channel conduit.

Key Words: Headwater stream; Nitrogen; Sources and transformations;

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